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Structure contours on the top and base of the M bed, the relationship of mineralization to structures, and the variation of the M bed thickness in the Tri-State District, Missouri, Kansas and Oklahoma

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STRUCTURE CONTOURS ON THE TOP AND BASE OF THE M BED,

THE RELATIONSHIP OF MINERALIZATION TO STRUCTURES,

AND THE VARIATION OF THE M BED THICKNESS

IN THE TRI-STATE DISTRICT,

MISSOURI, KANSAS AND OKLAHOMA

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ABSTRACT

Regional structure and thickness of a single horizon, the M bed, have been studied in the Tri-State district by picking the top and base of the M bed in the logs of 557 selected drill holes and contouring this data together with the aid of local detailed structural information available for individual mining fields. Structures determined from these data were compared to the positions of mined mineralization to determine the control of regional structure upon the localization of ore. Variations in the M bed thickness were compared to the positions of fields of mineralization to examine possible spatial relationships which they might show.

Among the 80 folds outlined in the fields of the Tri-State district, two-thirds of the synclines and one-third of the anticlines exhibit areally associated mineralization. The preference for synclines over anticlines suggests that the ore-forming solutions were moving downward at the time at which the ores were deposited.

The M bed exhibits remarkable variations in thickness in the Tri-State district from as little as eight feet to as much as 110 feet. In the Picher field strikingly concentric isopachous zones show a progressive decrease in thickness toward the center of the field. The Galena, Melrose and possibly the Waco fields show similar but less well defined thinning of the M bed. This close relationship between the M bed thickness and the fields of mineralization is

interpreted to have resulted from solution of the M bed limestone partly before mineralization and partly during the ore-forming process.

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CHAPTER I

INTRODUCTION

A. Purpose of Investigation

The pronounced northwesterly trend of major mining fields in the Tri-State district suggested to Dr. Richard D. Hagni that regional structure may be a controlling factor in the localization of fields of mineralization. In fall of 1964 he discussed that possibility with Mr. Edward H. Hare, Jr., Eagle-Picher district geologist, who also believed that a study of regional structure might show some relation to areas of mineralization. They interested the writer in collecting the necessary drill hole information and made suggestions relative to the drill holes selected.

The principal purpose of this structural study was to determine the relationship between regional structure and areas of zinc-lead mineralization. Structure was determined by drawing contours on the top and base of the M bed, the principal producing horizon in the district. The positions of synclines, anticlines, fold flanks and fault-troughs, determined on the top and base of the M bed, were compared to the positions of mined ore.

The thickness of the M bed, an additional result of this structural study, also was compared to the mined areas to study the possible regular variation in the M bed thickness with the areal locations of fields of mineralization in the Tri-State district.

B. Scope of Investigation

This study has been confined to the relationship of ore bodies to the M bed because approximately 75 per cent of the ore production has been from this horizon and because the top and base of the M bed are among the more reliable markers. Most of the mining fields in the Tri-State district have been included within the present study; only the Granby, Neck City-Alba, Racine-Spring City and Springfield fields have been omitted for lack of sufficient data.

It should be emphasized at this stage that the amount of information available to the writer varied greatly from area to area. In areas such as the Picher field more than sufficient drill hole data were available, but in other areas, particularly those distant from mining fields, very few drill logs were available. In spite of these difficulties, an attempt has been made to prepare structure contour maps from which a regional relationship between the ore bodies and the M bed structure might be established.

C. Location and Size of the Area

The Tri-State zinc and lead mining district comprises an area of about 2000 square miles in southwestern Missouri, northeastern Oklahoma and southeastern Kansas (Figures 1 and 2). It has been one of the most productive zinc and lead areas of the world.

Mining activity, which began as early as 1848, initially was confined to the Joplin field. Although mining activity

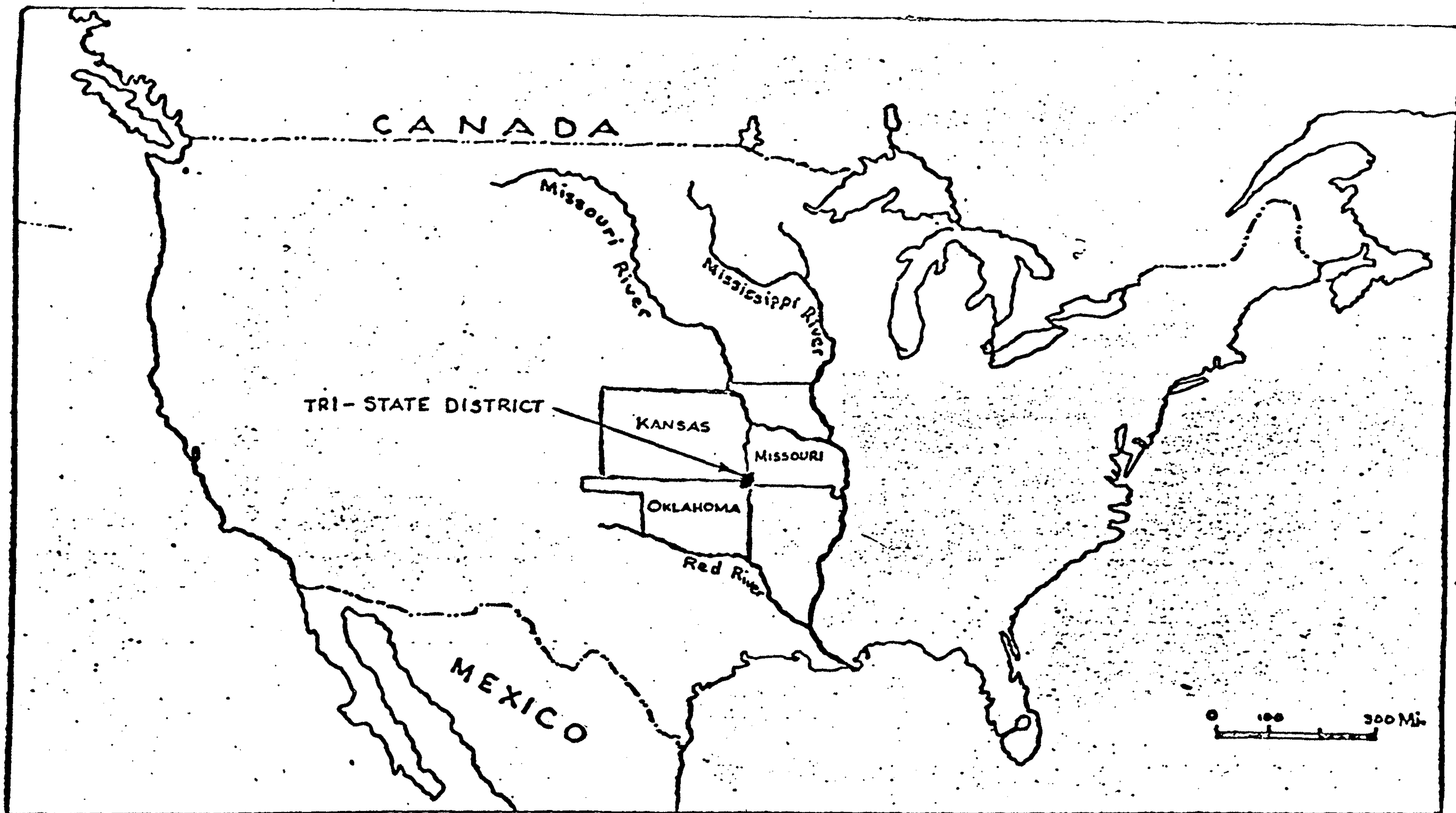

Figure 1. Index map showing the location of the Tri-State district in southwestern Missouri, southeastern Kansas and northeastern Oklahoma, U.S.A.

After Saadallah (1964)

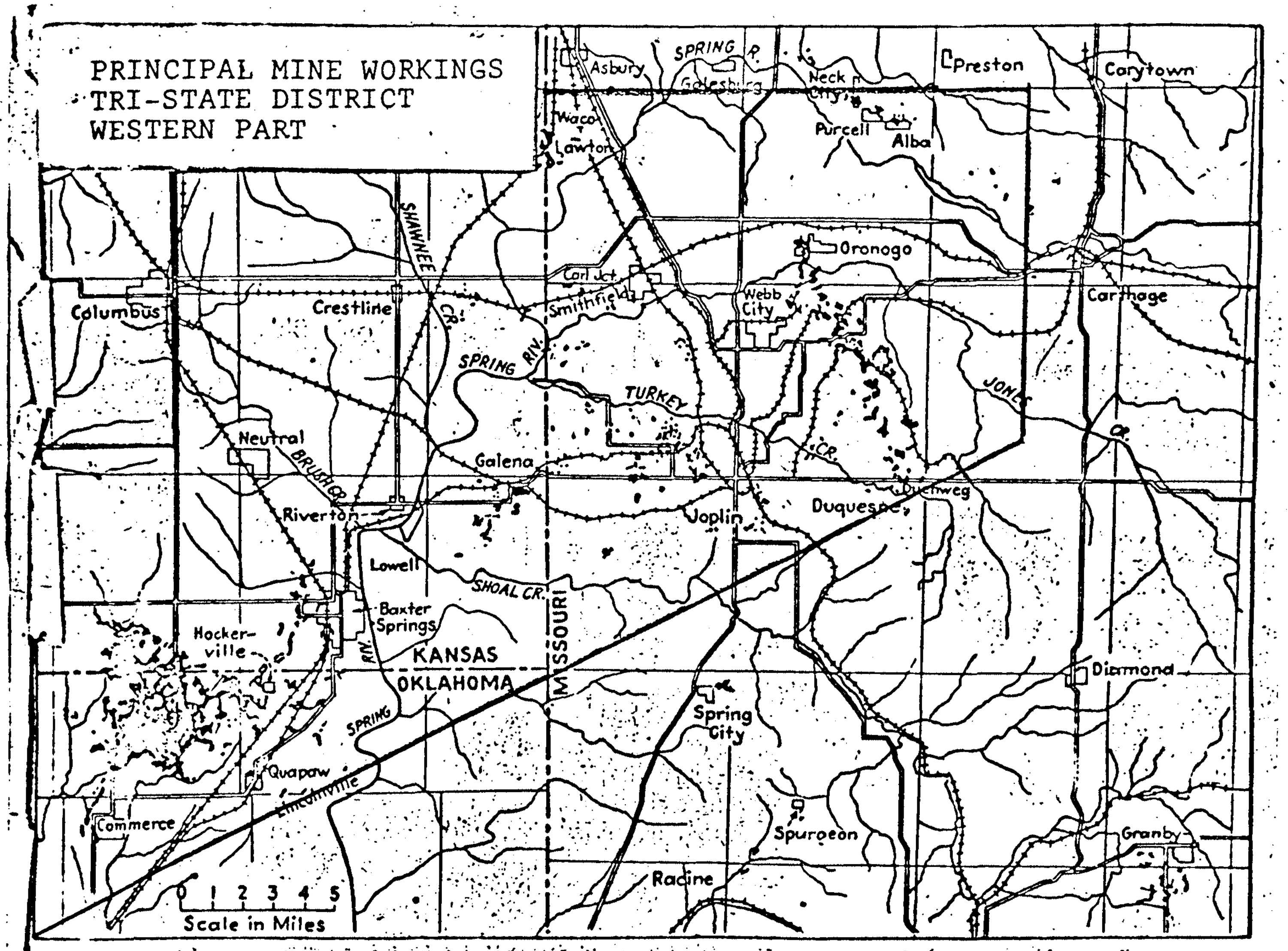

Figure 2

(After Fowler and Lyden, 1932)

has continued up to the present time, most of the lead and zinc production in recent years has come from the Picher field.

D. Physiography

The region comprising this investigation forms a part of the Springfield Plateau of the Ozark Plateaus Province, and the Cherokee Lowlands Province. The former, mainly in Missouri, is hilly and its surface is underlain by Mississippian formations; the latter section, mostly in Oklahoma, is flat and is underlain by Pennsylvanian formations.

According to Smith and Siebenthal (1907), the difference in elevation between the highest and lowest points in the district amounts to little more than 440 feet. The highest point is 1210 feet and the lowest point is 775 feet above the sea level. The area is drained principally by the southward flowing Neosho and Spring Rivers and by the Spring River tributaries,which are Center and Shoal Creeks. These streams are perennial and they carry abundant water. They originate outside the district, but in traversing it they receive important additions of ground water (Harvey and Maxwell, 1966).

E. Climate, Vegetation and Culture

The moderate climate and precipitation of the Tri-State region allows year-around mining and milling operations. The summer temperatures usually are well above 80 degrees.

Spring temperatures generally vary from 50 to 60 degrees. The average annual precipitation is about 26 inches.

Cultivated areas are found mainly along the stream and river bottoms. Good crops of wheat and average crops of corn are produced in Missouri. The stream valleys, which generally are broad, often a quarter to a half mile in width, are the most fertile.

The largest city in the district is Joplin. Miami, which lies at the southern edge, is the second largest city. Smaller towns are Webb City, Carthage, Carterville, Galena, Baxter Springs, Linconville, Picher, Commerce and Quapaw.

In the past, mining activity in Missouri was centered about the towns of Joplin, Granby, Webb City, Duenweg and Oronogo and to a lesser extent about Smithfield, Carl Junction, Waco, Spring City, Spurgeon, Neck City, Alba, Carthage and Springfield in Missouri. In the Oklahoma and Kansas portions of the district, past mining was centered about Baxter Springs and Galena,but the most recent mining has been centered around Cardin and Picher.

The district is traversed by the U. S. highways 66, 69, 71, 166 and interstate 44 and the state highways 7, 26, 43 and 57. The northern extension of the Will Rogers Turnpike reaches the southern edge of the district. The major railroad in the district is the St. Louis-San Francisco railroad.

F. Acknowledgments

The writer wishes to express thanks to Dr. R. D. Hagni, University of Missouri at Rolla, for his suggestion of the problem and for sustained guidance throughout the course of this investigation.

The writer is indebted to the Eagle-Picher Company for summer employment which allowed him access to their extensive drill hole records and especially to Mr. D. C. Brockie, Chief Geologist, Mr. E. H. Hare, Jr., District Geologist, and Mr. B. Kyser, all of whom helped the author interpret those logs.

Thanks are also due to the Missouri State Geological Survey for access to the file of drill logs, particularly to Mr. Charles Robertson for aid in the interpretation of some of those logs and to Mrs. Mary H. McCracken for helpful suggestions concerning the older formations in the Tri-State district.

Dr. A. C. Spreng, Professor, Department of Geology, University of Missouri at Rolla, offered helpful suggestions concerning stratigraphy and the drafting of the maps.

The writer wishes to thank Dr. P. D. Proctor, Dean, School of Science, University of Missouri at Rolla, for suggestions pertaining to the size measurements of structures.

Thanks are due to Mr. V. R. Shah for his help in drafting the maps.

G. Method of Investigation

The regional structure of the Tri-State district was studied by recording the depths to the top and base of the M bed in 557 drill hole logs. These depths were obtained from the drill log records of the Eagle-Picher Company in Cardin, Oklahoma, in some of which the top and base of the M bed had previously been located by the geologists of that Company. These logs, together with the ever-present assistance of the company geologists, enabled the writer to gain adequate experience for him to select the top and base of the M bed in drill hole logs in which those markers had not been previously indicated. Logs of this nature were encountered both in Eagle-Picher's records and in the drill log file at the Missouri Geological Survey.

The two depth figures for each drill hole were subtracted from its collar elevation as indicated on the log or as determined from a topographic map. The resultant elevation figures for the top and base of the M bed in each hole were plotted along with its location on a district mining map which had a scale of one inch to the mile. This map and basic elevation data appear as Figure 4 in this thesis. The term "NDE@" preceeds figures which indicate a maximum elevation for the top or base of the M bed in a hole which was not drilled deep enough to intersect that contact. An elevation figure followed by "or NDE" indicates an uncertainty as to whether the contact was reached or only nearly reached at that elevation.

Using the basic elevation data,three maps were prepared. The contour map of the base of the M bed was based on elevation of the M bed in 483 drill holes. The contour map of the top of the M bed is based on information from 540 drill holes.

Published structure maps for individual fields in the Tri-State district were used to aid in the drawing of contours in the respective fields. The value of their aid varied generally with the amount of information upon which they were based. Structure maps used to some degree were:

1. Tectonic Map Showing Structure Contours on Base of the M bed, Oklahoma-Kansas Mining Field (Fowler, 1960).
2. Structure Contour Map Showing the Elevation above the Sea and the Configuration of the Surface of the Grand Falls Chert (Smith and Siebenthal, 1907).
3. Contour Map of the Base of the Cherokee Shale in the Zinc and Lead district of southeastern Kansas (Pierce, 1935).
4. Structure Contour Map of the Short Creek Oolite, Ottawa County, Oklahoma (Speer, J. H., 1951).
5. Maps Showing Structural Geology and Dolomitized Areas in Part of the Picher Zinc-Lead Field (McKnight, 1944).

6. Investigations of Melrose Zinc-Lead District, Ottawa County, Oklahoma, and Cherokee County, Kansas (Knox, 1948).

An isopach map of the M bed was prepared by subtracting the elevation of the base of the M bed from that of its top for each drill hole. The isopach map is based on 447 drill holes.

CHAPTER II

GENERAL GEOLOGY OF THE TRI-STATE DISTRICT

A. Regional Stratigraphy

Eleven deep drill holes drilled in the Tri-State district which have penetrated the basement igneous rocks have revealed thicknesses of sedimentary strata varying from 294 to 1800 feet. The sedimentary strata, which vary in mineralogical composition and texture, have been subdivided into nineteen formations and groups. These are shown in Table I. Much of the following stratigraphic discussion is taken from Hagni (1962), who reviewed the literature.

The youngest exposed rocks in the region are unconsolidated "Lafayette" gravels of Tertiary age, which cap the low hills in the vicinity of Miami, Oklahoma, and those to the east of Springfield, Missouri. The youngest consolidated rocks, principally shales, are of Pennsylvanian age. Older Paleozoic rocks in the region are Mississippian limestones, Devonian Shales, Ordovician Dolomites and Sandstones and Cambrian Sandstones and Dolomites. Precambrian granites have been encountered in deep drill holes at a few localities in Oklahoma and Missouri.

1. Pennsylvanian System

The Pennsylvanian rocks of the Tri-State district belong to the Marmaton Group and the Cherokee Group of the Desmoinesian Series. The latter group, whose thickness ranges

TABLE I

Generalized Stratigraphic Section of the Tri-State District

System	Series	Formations (Groups)	Thickness in Feet
Pennsylvanian	Desmoinesian	Marmaton Group	0-350
		Cherokee Group	
- - - - - - - unconformity	- - - - - - - - - - - - -	- - - - - - - - - - - - - - - -	- - - - - - - -
	Chesterian	Carterville or Mayes	0-200
	Meramecian	St. Louis (?) Limestone	
Mississippian	unconformity - - - -	Warsaw Formation	42-190
		Keokuk Formation	30-130
	Osagean	Reeds Spring Formation	80-120
	unconformity - - - -	Fern Glen Formation	
	Kinderhookian	Northview Formation	
		Compton Formation	
Devono-Mississippian		Chattanooga Shale	0-10
- - - - - - - unconformity	- - - - - - - - - - - -	- - - - - - - - - - - - - - - -	- - - - - - - -
Ordovician		Cotter Dolomite	200-280
		Jefferson City Dolomite	200-235
	Canadian	Roubidoux Formation	150-180
		Gasconade Formation	0-330
Cambrian		Eminence Dolomite	0-140
	Croixian	Potosi Dolomite	0-220
		Bonneterre (?) Formation	
		Lamotte Sandstone	0-40
- - - - - - - unconformity	- - - - - - - - - - - -	- - - - - - - - - - - - - - - -	- - - - - - - -
Precambrian		Granites and Tuffs	

Modified after Fowler and Lyden (1932), Lyden 1949 from zero to 350 feet, comprise mainly shales and limestones. The formations of the Cherokee Group constitute the principal surface rocks in the Oklahoma and Kansas portions of the district. In the Missouri portion of the district they occur sporadically as outliers.

2. Mississippian System

The Mississippian System is subdivided into four series: Chesterian, Meramecian, Osagean, and Kinderhookian.

a. The Chesterian Series

The top of Mississippian is represented by Carterville Formation which is the sole member of the Chesterian Series. It consists of sandstone, limestone and shale. It underlies the Cherokee Group in the western part of the district, but it extends to the eastern margin of the district at Springfield, Missouri. The formation is extremely variable in thickness and may attain a maximum thickness of more than 200 feet in some sink structures. The Carterville Formation has been correlated with Fayetteville, Batesville and Hindsville formations.

b. The Meramecian Series

The St. Louis Limestone which constitutes the top of the Meramecian Series, is gray, dense and fine grained. Fowler and Lyden (1937) believe the St. Louis Limestone is discontinuous and occurs only locally in the Tri-State district, but Mary McCracken (oral communication) believes the formation is absent from the district.

An unconformity separates the Warsaw Formation from the overlying St. Louis Limestone. The Warsaw Formation, which consists of limestone, "cotton rock", and chert, has been subdivided into seven beds, lettered C through J. The general character of these beds is given in Table II. The chert content is the principal basis on which these beds are distinguished. The B bed consists of limestone, the C and E beds are limestones which contain chert nodules, the D and F beds are nearly all chert, and the G-H bed consists of thin bedded chert and limestone.

c. Osagean Series

The Osagean Series is composed of the Keokuk, Grand Falls, Reeds Spring and Fern Glen Formations.

The Keokuk Formation, which unconformably underlies the Warsaw Formation, comprises the K, L and M beds. The limestone in these beds is gray and medium to coarse grained. Chert nodules characterize the K and M beds and the L bed is very cherty. The M bed, which is the most productive bed in the district, in many places is clearly distinguished from the overlying L bed by an intervening oolite, called the Short Creek Oolite. The oolite constitutes a marker horizon commonly used for the surface and subsurface stratigraphic and structural studies. The M bed consists predominantly of limestone which is medium grained and gray in color. Within the ore bodies it is very vuggy or replaced by dolomite, jasperoid and sulfide minerals.

TABLE II

Stratigraphic Column of the Meramecian and Osagean Series in the Tri-State District

System	Series	Formation	Bed	Thickness in feet	Lithology	Importance as an ore body
Mississippian	Meramecian	St. Louis (?)	B	0-40	Limestone	Unimportant
		Warsaw	C	0-32	Limestone and chert nodules	Unimportant
			D	0-25	"Cotton rock" and chert	Unimportant
			E	0-8	Limestone and chert nodules	Minor importance
			F	0-15	"Cotton rock" and chert	Unimportant
			G H	0-20 0-20	Thin bedded limestone and chert	Important
			J	0-50	Glauconitic, shaly limestone and chert	Unimportant
	- - unconformity - - - -					
		Keokuk	K	0-10	Crinoidal limestone and chert nodules	Very important
			L	0-30	Chert	Unimportant
			M	4-6 0-30	Short Greek oolitic Member Limestone and chert nodules	Most important

TABLE II continued

Stratigraphic Column of the Meramecian and Osagean Series
in the Tri-State District

System	Series	Formation	Bed	Thickness in feet	Lithology	Importance as an ore body
	Osagean		N	20-80	Chert	Minor Important
			O	8-9	Thin bedded chert and limestone	Important
			P	8-11	Chert	Minor importance
		Grand Falls	Q	17-18	Thin bedded chert and limestone	Minor importance
	- - unconformity - -					
		Reeds Spring	R	80-120	Limestone and dark chert nodules	Important
		St. Joe		50	Limestone	Unimportant
	- - unconformity - -					

(modified after Fowler and Lyden, 1932, Lyden 1949, and Hagni 1962)

The Burlington Formation together with the Keokuk Formation averages approximately 200 feet in western Missouri, but the Burlington has not been found or it is inseparable from the overlying Keokuk Formation in the major portion of the district and particularly in and around the Picher field.

The Grand Falls Formation, typically developed in the Joplin and Baxter Springs fields where it is locally known as the "sheet ground" ore horizon and the "hog chaw flint", varies in thickness from 25 to 40 feet. The formation, which encompasses the beds N through Q, consists almost entirely of chert. The chert is smooth, cream colored and mottled, with subvitrious luster. Due to its tendency to fracture with very sharp edges, it is also known locally as "butcher knife flint".

The Reeds Spring Formation, which underlies the Grand Falls Formation, has been assigned the letter R. It is composed of a dark gray to almost black, dense and finely crystalline cherty limestone. It contains chert which is dense, smooth, and blue to black in color.

The Fern Glen Formation is a bluish gray, fine grained, non-cherty limestone. It has not been assigned a letter, for it lies beneath the mined ore.

d. Kinderhookian Series

The Kinderhookian Series includes the Northview Shale and the Compton Limestone. These formations occur principally toward the eastern margin of the district. They have not been encountered in any of the mines.

3. Devono-Mississippian Beds

The Devono-Mississippian Chattanooga Shale has been identified in some parts of the district by Siebenthal (1908).

4. Ordovician System

The Ordovician System, whose thickness varies from 700 to 1000 feet, is composed of dolomites and sandstones. The formations of this system recognized in the Tri-State district are from youngest to oldest: Cotter Dolomite, Jefferson City Dolomite, Roubidoux Sandstone, Gasconade Dolomite and the Gunter Sandstone.

5. Cambrian System

The Cambrian System in the district is composed of sandstones and dolomites which average 800 feet in thickness. The different formations from youngest to oldest are: Eminence Dolomite, Potosi Dolomite, Bonneterre Dolomite and Lamotte Sandstone.

6. Precambrian Rocks

Precambrian granites are known only from a few deep drill holes in the district, but granites outcrop south of the district, at Spavinaw, Oklahoma. Southwest of the district tuffs have been reported from drill holes which have reached the basement (Ham, 1961).

The above stratigraphic subdivisions used in the district are used by the Missouri Geological Survey, but with slight modifications. The Short Creek Oolite is selected as the break between Warsaw and Keokuk-Burlington Formations. Keokuk-Burlington is used as a formational unit since it generally cannot be adequately subdivided in subsurface studies. The St. Joe is used as a group name comprising the Pierson, Northview and Compton Formations. The presence of St. Louis Formation in the Tri-State district may be open to question (Mary McCracken, oral communication).

B. Regional Structure

The structures of regional extent in and contiguous to the Tri-State district are treated in this section. More detailed aspects of the structures are treated in a subsequent section of this thesis.

The broad structural features of the region include the following: regional dip of the Ozark dome, Joplin anticline, Horse Creek anticline, Seneca fault-trough, Cow Creek anticline, Lawton trough, Miami fault trough, Bendelari trough, Ritchey fault, the Chesapeake fault and a small fault near Granby. The general positions and trends of these structures are shown in Figure 3.

The Ozark dome, whose axis lies to the southeast of the district, produces a regional dip of the strata which varies from about eight to fifteen feet per mile to the northwest.

The Joplin anticline was first described by Smith and Siebenthal (1907), who discovered the structure by preparing a structure contour map on the top of the Grand Falls

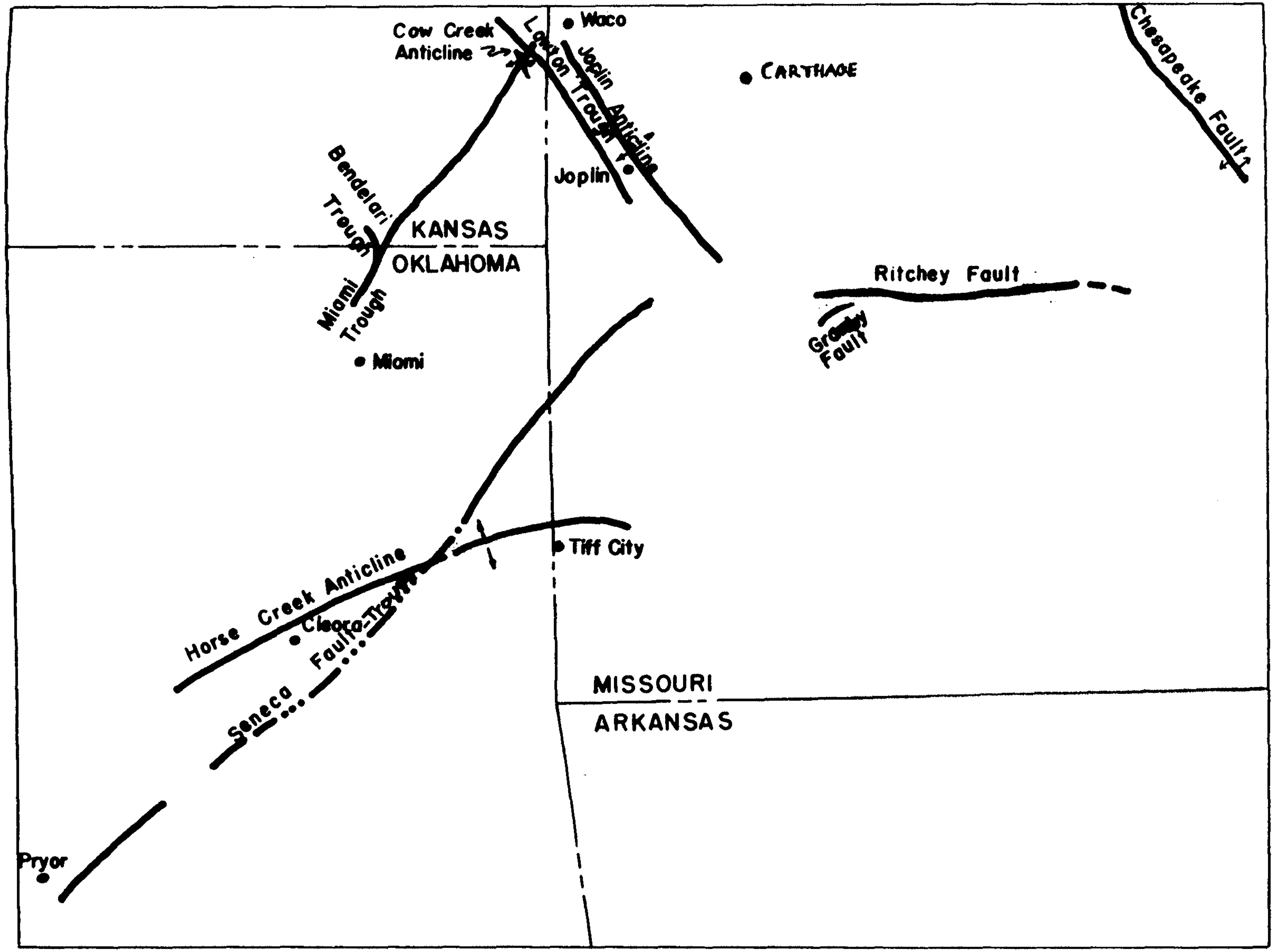

FIGURE 3

MAJOR STRUCTURAL FEATURES OF THE TRI-STATE DISTRICT

(MODIFIED AFTER R. D. HAGNI, 1962)

SCALE:

Formation in the Joplin area. Their structure map, which was based upon drill hole information and surface exposures, shows a broad northwest trending anticline which enters the district from south just east of Shoal Creek and bears northwestward to the vicinity of Waco. According to these authors, the anticline is much steeper on the western limb than on the eastern limb. The inequalities of elevation arising from the orogenic movement which resulted in the formation of the anticline amount to 150 to 200 feet. The anticline cannot be recognized from dips or surface features except in places where streams cut across the axis and expose the Grand Falls chert. Smith and Siebenthal believed the fold may develop into a fault between Joplin and Smithfield. The crest of the structure is more than 100 feet higher than the flanks.

The Horse Creek anticline was first described by Siebenthal (1908) as an asymmetrical fold with gently dipping limbs. Its northwest limb dips two degrees and the southeast limb dips from five to eighteen degrees. This anticline lies fifteen miles south of the district and can be observed about ten miles east of Tiff City, Missouri, from whence it trends due west to the Missouri-Oklahoma line and then west-southwest to the vicinity of Big Cabin, Oklahoma. The present writer's work does not include the area of this structure.

The Seneca fault-trough or syncline was first described by Siebenthal (1908), who called the structure a double fault. Weidman (1932) believed it to be a syncline. This structure, which crosses the Horse Creek anticline about fifteen miles south of the district, extends from Seneca, Missouri, southward to Coweta, Oklahoma. Displacement along this structure varies from 90 to 140 feet. The structure lies just south of the area studied by the present writer.

The Cow Creek anticline also was described by Smith and Siebenthal (1907), who prepared a structure contour map on top of the Grand Falls Formation. It extends a distance of a little over two miles. According to the authors, the eastern limb of this anticline is much steeper than the western limb. It is a short and rather sharp anticline in the Cherokee Formation. This structure was detected in the present writer's work on the underlying Mississippian beds.

The Lawton trough was first described by Pierce (1935), who outlined the structure in the southeastern portion of Kansas by structure contours on the base of the Cherokee Shale. This structure is discontinuous and trends nearly parallel to, and about three or four miles from, the Joplin anticline. The maximum difference in elevation of the Cherokee Shale caused by the structure is about 120 feet. This structure at the base of the Pennsylvanian is not well exhibited on the present writer's Mississippian M bed structure maps.

The Miami fault-trough, which is the largest structure in the Picher field, was first described in detail by Fowler and Lyden (1932), but it is best shown by a more recent Picher field structure map based on the base of the M bed (Fowler, 1960). The northeast trending structure is known both from drilling and from its occurrence in some mines. Fowler and Lyden (1932) believe it to be a series of graben fault blocks or troughs. Weidman (1932) believed it to be a result of underground solution activity. Pierce (1935) claimed evidence for all the three processes along the structures. Naething (1926) thought that the Miami structure represented a pre-Chester erosion channel, controlled by pre-Chester faulting, which suffered post-Pennsylvanian faulting. Lyden (1950 believes that the Miami structure contains along its trend a series of elongated graben fault blocks, 500 to 1200 feet wide, and one-half to three-fourths of a mile long, that dropped 100 to 250 feet. The limbs of this structure appear as distinct faults in some mines and as breccia zones in other mines. The present writer's structure maps show the Miami trough as two northeast trending segments.

The Bendelari trough was described by Fowler and Lyden (1932), and its extent was shown on maps by Lyden (1950) and Fowler (1960). It trends northwest from the Miami structure near the center of the Picher field. The present writer's regional structure maps show only the broad outline of the Bendelari trough.

The Ritchey fault was mapped in the field by Rutledge (1929). It is the normal type of fault. The south side of the Ritchey fault has moved downward about 150 feet relative to the north side in the vicinity of Ritchey. Brecciation and steeply dipping strata which should be of common occurrence along a fault plane are not very conspicuous. Broken Mississippian rocks present to the north and south of the fault plane suggest a late Mississippian age for movement along the fault.

The Chesapeake fault, originally called the Chesapeake anticline by Sheppard (1898), was mapped by Rutledge (1929) as a fault. This fault is known to extend from the center of the east line of Sec. 12, T. 27 N., R. 25 W., some 25 miles in a general northwest direction across Lawrence County and to continue an unknown distance into Dade County. Movement along the fault, which generally varies from 150 feet to 170 feet, decreases toward the southeast to as little as 50 feet in Christian County. Brecciation along the fault plane is not conspicuous, although the rocks locally are shattered in the immediate proximity of the structure. The time of faulting is believed by Rutledge to be late Mississippian.

A short fault, about one and one-half miles long and located west of the town of Granby, has been mapped by Rutledge (1929), although the structure appeared earlier on a manuscript map by J. Theil. The Granby fault trace strikes N. 76° E., and the northwest side has moved down relative to the south side. The amount of movement of the fault decreases to the northeast.

C. Ore Deposits

The ore deposits of the Tri-State district are characterized by their location close to the earth's surface, their wide areal extent and the lack of any igneous rocks which could be the source of hydrothermal solutions. They may be divided on the basis of their structure and location into two groups:

1. deposits localized in sink structures.
2. deposits localized in fractured and brecciated Mississippian Formations.

The ores of the first group occur mainly around the margins of the sink structures, but sulfides also are disseminated throughout the Pennsylvanian Shale and adjacent rocks. Such deposits are roughly circular in shape and locally they are called "circles".

The second group of the deposits is confined to fractured and brecciated Mississippian cherts and limestone below the Pennsylvanian Shale. Deposits of this group fall into two categories:

1. Elongated ore bodies of chert breccias called "runs" which generally follow the bedding planes and occasionally break through to other beds. These ore bodies are localized in thin bedded, less competent strata such as the D, E, G, H, K and M beds. Approximately 75 per cent of the ore produced in the Tri-State district has come from the M bed.

2. Layered and partly broken chert bodies. These are locally called "sheet ground" deposits. They vary in thickness from ten to thirty feet, and they have enormous lateral extents of a thousand feet or more. These ore bodies are localized in the O, P and Q beds.

The mineralogy of the ore deposits has been discussed in detail by Hagni (1962), who described fifty-one minerals from the district. Sphalerite and galena are the chief ore minerals of commercial interest. Less common sulfides are chalcopyrite, marcasite and pyrite. Quartz, dolomite, and calcite constitute the principal non-sulfide gangue minerals.

The detailed paragenesis of these minerals has been recently described by Hagni and Grawe (1963). Mineral zoning has been shown by Lyden (1950) and McKnight (1942). The alteration of the predominantly allochemical host rock limestone to a recrystallized state consisting mainly of sparry calcite has been recently described by Hagni and Saadallah (1965).

Clay minerals are present locally in pockets of pasty gray or green gouge, often referred to as selvage, in some muddy slime, and in shale which fill the crevices in some deposits. These muds are only partly consolidated and appear to have reached their present positions in very recent times.

The origin of the Tri-State ore deposits has been recently reviewed by Hagni and Grawe (1963). These authors show that most of the observed features of the deposits have received dual interpretation. One group of geologists believe the deposits have formed from descending meteoric or ground waters of normal or near surface temperatures. An opposing group interprets the same facts to indicate that the ores formed from heated solutions rising from an undisclosed deep-seated igneous source. Some geologists have suggested additional minor variations to these two main hypotheses of origin. The controversy is unresolved.

CHAPTER III

REGIONAL STRUCTURE AND RELATIONSHIP TO MINERALIZATION

A. Previous Investigations

One of the earliest publications on the structures in the Tri-State district was that by Jenney (1893) who mistakenly interpreted local slump structures in the Granby field to be deep-seated vertical fissures.

As early as 1894, Winslow and Robertson in a detailed description of those mines which were productive at that time in the Joplin field, described local fractures and openings, produced by solution of limestone, which subsequently served as the conduits for the ore-bearing solutions.

Buckley and Buehler (1905) discussed the geology of the Granby field in considerable detail but they did not study the details of the structure in that field. Their only reference to structure was that of the regional northerly dip of about 25 feet to the mile as shown by the elevations of the Short Creek Oolite in different localities over that field.

Haworth (1905) described the general geology of the Galena field in a comprehensive report. Among the structural features discussed were fractures and faults, but he did not prepare a structure contour map to show any folding that might exist in that field.

One of the more important publications on the Tri-State district is the Joplin Folio by Smith and Siebenthal (1907). It included a structure contour map on which contours drawn on the top of the Grand Falls Formation first outlined the Joplin anticline in the Joplin field. Local structure maps for other fields included the Webb City, Carterville and Oronogo fields.

Siebenthal (1915), in a treatise dealing primarily with the genesis of the Tri-State ores, described the Ozark uplift as a broad geanticline upon which the faults and folds of the region were superimposed.

Fowler and Lyden (1932) have intensively studied the structure in many mines, especially those in the Picher field. They and their associates mapped the ore bodies and their relationships to local structures. Their detailed structure contour maps on the base of the M bed in the Webber and Blue Goose mines show a close relationship between mineralization and minor folds and fractures. The Miami trough was first described and pictured in this paper.

Weidman (1932) described structural relations similar to those illustrated by Fowler and Lyden, and on a map of the Picher field showed the tendency for individual runs to trend predominantly in northeasterly and northwesterly directions.

Pierce (1935) prepared a structure contour map on the base of the Pennsylvanian, an unconformity surface, in an attempt to determine the relationship between the base of the Cherokee Shale and the underlying Mississippian limestone. His map, which was confined to the Kansas portion of the district, showed the configuration of the base of the Cherokee Shale and also exhibits the general outline of the Miami fault-trough.

Fowler (1938), in a paper discussing the subsurface structure of the Picher field, included a map showing local structures in the Woodchuck mine. Five years later, Fowler published additional base of M bed structure contour maps for the Webber and Blue Goose mines in the Picher field. These maps showed the minor anticlines and synclines and their relationship to the mined ore.

An unpublished thesis by Speer (1951) dealt with the Short Creek Oolite in the Ottawa County, Oklahoma. He found that marker horizon to extend over a large area which permitted him to prepare a structure contour map based upon the Short Creek Oolite. Speer's map shows the Miami fault-trough as well as the Seneca syncline, but some of the structural interpretations appear to be at odds with the present writer's findings.

Lyden (1950), in a paper on structural and mineralization aspects of the Picher field, emphasized local folding and fracturing as ore controls. A structure contour map on the top of the L bed and maps showing fracturing in G-H, J and K beds in several adjacent mines in the northwest portion of the Picher field and a structure contour map on the top of the N bed in Webber mine illustrated these local structural controls. The quite unique pipe slumps in the Webber mine also were illustrated.

Fowler, et al., (1955) published additional structural maps with contours drawn on the M, O and R beds in the Blue Goose mine. This structural work again emphasized the importance of local pre-mineral folds, fractures and movements along the bedding planes.

In 1960, Fowler published a colored map showing the elevations of the base of the M bed in the Picher field. This map outlines the Miami and Bendelari fault-troughs and folds in that field.

All of the previous investigations have dealt with local structures within specific mines or were restricted to certain fields; recent published structural studies especially have been confined to the Picher field. The present investigation is an attempt to analyze the importance of regional structure of the district in the localization of mineralization.

B. Preparation of Structure Maps

This section describes the nature of the information upon which the structure contour and thickness maps of the present study are based. The main source of the basic data was the drill log catalogue in the Cardin, Oklahoma, office of the Eagle-Picher Mining and Smelting Company. Their drill hole records for some areas, such as most of the Picher field and nearby vicinity, were very abundant. In such areas four drill holes per square mile were selected to yield information for this regional study. Outside the Picher field much less information was available because those areas have not been extensively mined nor intensively drilled. In portions of those areas less than four drill holes per square mile were available.

The top and base of the M bed were obtained by a careful study of numerous drill logs. Preparatory to selecting a drill log for a particular section, many drill logs from that vicinity were studied. The drill log eventually selected was that one which afforded the most reliable top and base contacts of the M bed. In those logs in which the Short Creek Oolite was indicated, it served as a reliable contact for the top of the M bed. For drill logs in which the Oolite was not indicated, the top of the M bed was determined by carefully distinguishing the overlying L bed which is characterized by its content of massive gray chert or cotton rock. Additional features that were considered in this determination were the predominance of limestone and the greater amount of mineralization in the M bed.

The base of the M bed was readily and precisely determined in most drill logs because the underlying N bed consists predominantly of chert and it is nearly always barren of sulfide mineralization.

The depths to the top and base of the M bed were converted to elevations above sea level. For logs whose collar elevations were lacking, approximate elevations were obtained by locating the drill hole on appropriate topographic sheets published by the United States Geological Survey. Such recourse caused a small error in some structural elevations.

An additional source for drill hole information, especially for the Missouri portion of the Tri-State district, was the Missouri State Geological Survey. In most of those logs the top of the M bed was marked by the Short Creek Oolite and the base of the M bed was indicated by the top of the underlying Grand Falls Chert.

These data were plotted on maps, and structure contours were drawn on the top and base of the M bed with a uniform contour interval of 25 feet. In the areas with significant drill hole information, that is, those areas with at least one drill hole per square mile, solid contour lines were drawn. In the areas with moderate drill hole information, i.e. those areas with one drill hole per two sections, dashed contour lines were drawn. In the areas of insufficient data, dotted contour lines were drawn with the aid of published local structure maps where available. For instance, in some parts of the Missouri portion of the district, very few reliable drill hole data were available and dotted contours as drawn necessarily rely heavily upon local structure contour maps published by Smith and Siebenthal (1907). Dotted contour lines drawn on the top of the M bed in some places were aided by the general trend of the contour lines on the base of the M bed in the same vicinities.

C. Structures Determined On The Base of the M Bed and Their Relationship To Mineralization

1. Tri-State District

a. Structures

The structure map prepared by drawing contours on the base of the M bed exhibits 56 structures in the mineralized portions of the Tri-State district considered in this study (Figure 5). These structures are grouped into synclines, anticlines and faults. Of the structures considered by this study, 24 are synclines, 30 are anticlines and two are faults -- the northeast trending Miami fault and the northwest trending Bendelari trough. In addition to folds and faults, 48 flanks occurring between those folds have been considered. All four types of structures and their measured characteristics are listed in Appendix 1.

The folds may be subdivided according to their areal extents into three groups: major, moderate and small structures. The areal extents of the folds were determined by multiplying the distance between the mid points of their flanks by their length. Major folds are defined in this thesis as those whose areal extents are greater than 40 million square feet, moderate size structures have areal extents between 20 million square feet and 40 million square feet, and small structures are those whose areal extents are less than 20 million square feet. Among the 54 folds, eight anticlines and three synclines have major dimensions, thirteen anticlines and twelve synclines are of moderate size, and nine anticlines and nine synclines have small areal extents. The two fault-troughs are major structures.

Based upon their cross-sectional shapes, the folds have been categorized as: broad symmetrical, narrow symmetrical, broad asymmetrical and narrow asymmetrical.

The most prominent structural trend is in a northwest direction. Less commonly, the traces of the fold axes are oriented in a northeast direction. Folds rarely appear to have an east-west and north-south strike.

b. Relationship Between Mineralization And Structures

The principal purpose of this study was to examine the relationship between regional structure brought out by the structural contouring and localization of areas of mineralization. The intensity of mineralization, for the purpose of this study, was assumed to be equivalent to the areal extent of the mined ore. An evaluation of intensity of mineralization beyond that revealed by mining activity was beyond the scope of this thesis. In order to compare intensity of mineralization to the types of structures, four groups of intensity were arbitrarily chosen: intense, moderate, small and little. Intense mineralization refers in this thesis to areas in which more than 50 per cent of that area appears on the district mining map (one inch equals one mile) to have been mined. Moderate intensity of mineralization refers to those areas in which 20 to 50 per cent of the area appears from the district mine map to be mined. Small refers to those areas in which ten to 20 per cent of the area appears to have been mined. Little mineralization denotes those areas in which only small pockets of mined land are plotted on the district map.

Among the total of 56 structures brought out in the various fields of the Tri-State district by the structure map on the base of the M bed, 23 structures appear to have areally related mineralization. Areally related mineralization is considered in this study to be that which is located along the axis of a structure or, less commonly, that located at the nose of a fold. Areas of mined ore which trend across a structure are considered not to be areally related to the regional structures outlined in this study. A tabular summary of these relationships between mineralization and structures appears as Table III. The detailed relationships are indicated in Appendix 1 for each of the structures which are numbered on the structure map (Figure 5).

The fault-trough structures exhibit the most consistent areal relationship with mineralization. All such structures shown by the structure map have closely associated mineralization. Intense but discontinuous mineralization as shown by the mined areas appears either to be co-axial or to be

TABLE III

SUMMARY OF THE RELATIONSHIPS OF MINERALIZATION TO STRUCTURES DETERMINED ON THE BASE OF THE M BED

Synclines with Related Mineralization

	Major	Moderate	Small	Total
Number of Structures Mineralized	3	9	3	15
Per Cent of each Size Group that is mineralized	100%	75%	33%	62%

Anticlines with Related Mineralization

	Major	Moderate	Small	Total
Number of Structures Mineralized	3	3	2	8
Per Cent of Each Size Group that is mineralized	37%	23%	22%	27%

Flanks with Related Mineralization

Number of Structures Mineralized	12
Per Cent of Flanks that are mineralized	25%

Fault-Troughs with Related Mineralization

Number of Structures Mineralized	2
Per Cent of Fault-Troughs that are mineralized	100%

parallel but offset to one side of the structures. However, only two fault-troughs were outlined in the portion of the district considered by this study.

The synclines show a moderately close relationship to mineralization, one which is more consistent than that of the anticlines. Among the total 24 synclines, fifteen structures, or 62 per cent, appear to have areally related mineralization.

Subdividing the synclines according to size, two major synclines have some related mineralization and one major structure has a little areally related mineralization. Of the twelve moderate sized synclines, three have areally related intense mineralization, three have moderate mineralization and three exhibit some mineralization. With respect to the nine small synclines, seven have moderate mineralization and two have some mineralization. Although the larger synclines are less common they tend more to have areally related mineralization than do the smaller synclines.

Only eight, or 27 per cent, of the 30 anticlines determined by the base of the M bed contouring appear to have related mineralization. Among the eight major anticlines, two exhibit intense mineralization and one has moderate mineralization. Of the thirteen moderate size anticlines, two have areally related moderate mineralization and one has intense mineralization. Among the nine small anticlines, one has intense mineralization and the other has a little mineralization.

Between the above folds 48 flanks were listed in the portion of the Tri-State district studied. Of the 48 flanks, three appear to have areally related intense mineralization, five exhibit moderate mineralization, one shows some mineralization and three have a little mineralization.

The various structures and particularly their relationship with mineralized areas exhibit considerable variation from field to field in the district. The character of these variations is described for each field in the following sections.

2. Picher field

a. Structures

In the Picher field portion of the district, 21 regional structures were revealed by the base of the M bed structure contour map. Of these structures, twelve are anticlines, six are synclines, one is a fan-shaped fold and two are fault-troughs, the Miami trough, which is represented here as two disconnected segments, and the Bendelari trough. In addition to these structures, seventeen flanks between the folds have been considered separately.

Of the twelve anticlines, five fall into those termed major structures in this thesis, three are of moderate size and four are small. With regard to their shapes, nine anticlines are symmetrical and three are asymmetrical; most of them are rather broad in cross-section.

From a total of six regional synclines in the Picher field, three are of moderate size and three are small. All but one are symmetrical and broad.

The measured strike of the axial trace of each fold is recorded in Appendix 1, but the trends of their axes can be summarized here. The most common structural trend is northwesterly and eleven folds trend to the northwest, but seven trend northeasterly.

b. Relationship Between Mineralization and Structures

Of the twenty structures outlined by this study in the Picher field, twelve exhibit areally associated mineralization. Of these structures, five are anticlines, five are synclines and two are fault-troughs. Two of the five anticlines exhibit intense mineralization, two have moderate and one shows some mineralization. An example of mineralization which appears to be related to an anticline is structure number thirteen.

Only one of the five synclines exhibit intense mineralization, three show moderate and one has some mineralization. An excellent example of a syncline which exhibits a co-axial area of associated mineralization is structure number three.

Both the southwestern portion and the northeastern portion of the Miami fault-trough and the Bendelari fault-trough exhibit closely associated intense mineralization as described in the previous section. From the viewpoint of this regional structure study, the fault-trough structures show a very close relationship to mineralization. Fowler and Lyden (1932) and Fowler (1943) have shown similar relationships on detailed structure maps.

Among the seventeen flanks listed, eight have related mineralization which varies from intense to little in amount. Exceptionally, mineralization cuts across a structure or a flank such as that shown by structure number six.

3. Quapaw-Baxter Springs field

a. Structures

In the Quapaw-Baxter Springs field, three anticlines and two synclines were outlined by structure contours on the base of the M bed. All three anticlines and one syncline fall in the category of small structures. The remaining syncline is of moderate size. All of the folds have been classified as symmetrical. In the analysis of the regional structural position of mineralization, four flanks have been considered in this field.

b. Relationship Between Mineralization and Structures

Although the mineralization in the Quapaw-Baxter Springs field varies from moderate to intense, it appears to be essentially unrelated to the structures outlined in that area. Only the north flank of structure number 26 exhibits what might be interpreted as areally associated mineralization.

4. Melrose field

a. Structures

In the Melrose field drilling is close-spaced, but its localized nature limits the drawing of regional structure contour lines. Within the frame work of that limitation, one moderate sized, broad, symmetrical anticline and one small, symmetrical, narrow syncline appear to be outlined in the field. The flank between these folds was considered in the study of mineralized areas.

b. Relationship Between Mineralization and Structures

In the Melrose field some mineralization occurs along the trough of the syncline, but the other structure does not exhibit areally associated mineralization.

5. Galena field

a. Structures

In the Galena field eight structures have been determined. Of these structures, four are synclines and four are anticlines. All four of the anticlines are symmetrical structures, but two are of moderate size and two are small. From a total of four synclines, two are of major size, one is a moderate structure and one is a small structure. Of the four synclines three are symmetrical and one is asymmetrical. In addition to these structures, six flanks between the folds have been considered in the study of localization of mineralization.

b. Relationship Between Mineralization and Structures

Of the four synclines in the Galena field three exhibit areally associated mineralization, and show some mineralization. An example of mineralization which appears to be related to a syncline is structure number 29. In one instance, along the north flank of structure number 29, mineralization traverses the structure.

6. Joplin field

a. Structures

In the Joplin field six structures are outlined by the base of the M bed map. Of these structures three are anticlines and three are synclines. The three anticlines are symmetrical; each of the three size groups are represented. All three synclines are of moderate size; two of the three are symmetrical.

b. Relationship Between Mineralization and Structures

Of the three synclines in the Joplin field two exhibit areally associated mineralization and the other shows some mineralization. A good example of mineralization which is associated with a syncline is that of structure number 36. Only one anticline shows associated mineralization. Of the five flanks two have related mineralization which varies from intense to little in amount.

7. Oronogo-Webb City-Carterville-Duenweg field

a. Structures

In the Oronogo-Webb City-Carterville-Duenweg field four structures have been outlined by the structure contours on the base of the M bed. Two structures are anticlines, one of which is a major structure and the other is of moderate size. Two are synclines, one moderate sized, the other small. All four structures are symmetrical. In addition to these folds two flanks between the folds have been considered separately.

b. Relationship Between Mineralization and Structures

All the folds in the Oronogo-Webb City-Carterville-Duenweg field appear to exhibit areally associated moderate to intense mineralization. A good example of mineralization which is related to an anticline is structure number 44. One flank has related moderate mineralization, but mineralization cuts across the other flank, the east flank of structure number 45.

8. Klondike-Smithfield-Carl Junction-Thomas field

a. Structures

In the Klondike-Smithfield-Carl Junction-Thomas field there are three anticlines and three synclines. One anticline is a major structure and two anticlines are small structures. Each of the three size categories are represented by a single syncline. All of the anticlines are symmetrical, two of the synclines are asymmetrical. Five flanks between the folds have been considered.

b. Relationship Between Mineralization and Structures

One-half of the folds in the Klondike-Smithfield-Carl Junction-Thomas field, namely two synclines and one anticline, exhibit related mineralization. However, the intensity of mineralization range only a little to some. Two of the flanks have a little mineralization.

9. Badger field

a. Structures

In the Badger field one anticline and one syncline have been delineated. Both of the structures are moderate in size and symmetrical.

b. Relationship Between Mineralization and Structures

Neither of the two structures in the Badger field appear to exhibit related mineralization. Some mineralization is present to the west of the structures.

10. Waco field

a. Structures

The structures considered in this thesis lie to the west of the Waco field. Two synclines and an anticline were outlined on the base of the M bed structure map. Two of the structures are of moderate size and one is a small structure. The structures are symmetrical in shape.

b. Relationship Between Mineralization and Structures

Since the three structures described above are located to the west of the mined area in the Waco field it was not possible to ascertain their relationship to mineralization.

D. Structures on the Top of the M Bed and Their Relationship to Mineralization

1. Tri-State District

a. Structures

The structure map prepared by drawing contours on the top of the M bed exhibits 50 structures in the various fields of the Tri-State district considered in this study (Figure 6). These structures are very similar in size and location to those determined on the base of the M bed. They include 23 synclines, 23 anticlines and two fault-troughs. In addition to the folds and faults, 46 flanks occurring between these folds have been considered. All the structures are numbered on the map (Figure 6) and their measured characteristics are listed in Appendix 2.

Eight anticlines and three synclines have major dimensions, seven anticlines and seven synclines are moderate sized, eight anticlines and eleven synclines have small areal extents. The two fault-troughs are major structures. Most of the folds have symmetrical shapes, but some have an asymmetrical shape.

The most prominent structural trend is in a northwest direction. Less commonly the traces of the fold axes are oriented in a northeast direction, and rarely they appear to have an east-west or north-south trend.

b. Relationship Between Mineralization and Structures

Among the total of 50 structures in the Tri-State district brought out by the structure map on the top of the M bed, 28 folds and two fault-troughs appear to have areally related mineralization. These relationships are summarized in Table IV and the detailed measured relationships are given in Appendix 2.

The fault-troughs again exhibit the most consistent relationship with mineralization. The southwestern portion of the Miami fault exhibits an especially close relationship to narrow linear areas of mined ore.

The regional synclines depicted by the methods of this study show a much closer relationship with mineralization than do the anticlines. Among the 23 synclines, eighteen structures, or 77 per cent, appear to have areally related mineralization. Subdividing these synclines according to size, two major synclines have some areally related mineralization and one has a little mineralization. Of the seven moderate sized synclines, one has related intense mineralization, two have moderate mineralization and four exhibit some mineralization. With respect to the eight small synclines, one has intense-moderate mineralization, two have moderate mineralization and three exhibit some mineralization. Thus, the larger synclines tend more to have areally

TABLE IV

SUMMARY OF THE RELATIONSHIPS OF MINERALIZATION TO STRUCTURES DETERMINED ON THE TOP OF THE M BED

Synclines with Related Mineralization

	Major	Moderate	Small	Total
Number of Structures Mineralized	3	7	8	18
Per Cent of Each Size Group that is Mineralized	100%	77%	72%	77%

Anticlines with Related Mineralization

	Major	Moderate	Small	Total
Number of Structures Mineralized	5	0	5	10
Per Cent of Each Size Group that is Mineralized	62%	0	62%	43%

Flanks with Related Mineralization

Number of Structures Mineralized	20
Per Cent of Flanks that are mineralized	43%

Fault-Troughs with Related Mineralization

Number of Structures Mineralized	2
Per Cent of Fault-troughs that are Mineralized	100%

related mineralization than do the smaller ones.

Only ten, or 43 per cent, of the 23 anticlines determined by the top of the M bed contouring have related mineralization. Among the five major anticlines which have related mineralization, the intensity of such mineralization varies from little to intense. Among the five small anticlines, one exhibits intense mineralization and three show a little mineralization. None of the moderate sized anticlines have related mineralization.

Of the 46 flanks listed, one has areally related mineralization, one exhibits intense to moderate mineralization, six have moderate, three show some mineralization and nine have only a little mineralization.

2. Picher field

a. Structures

The Picher field has been the principal producing area in the Tri-State district. In this portion of the district the regional contouring technique used in this study has outlined twelve structures on the top of the M bed. These include seven anticlines, five synclines, one basin-shaped structure and two fault-troughs. The Miami fault-trough is represented by a southwestern and a northeastern segment; the Bendelari fault-trough trends northwesterly. In addition to these folds and faults, fourteen flanks between the folds have been considered.

The seven anticlines exhibit a variety of sizes and shapes. One anticline falls in the category of major structures, three are of moderate size and the remaining three are small. With regard to their shapes, five are symmetrical and two are asymmetrical. Three of the symmetrical anticlines are broad and two are narrow in cross-section. Only one of the five synclines in the Picher field is of moderate size, the remaining four are of small size.

The trends of the traces of the fold axes are partitioned into eight to the northwest and six to the northeast. The Miami fault-trough trends northeasterly in contrast to the Bendelari fault-trough which trends to the northwest.

b. Relationship Between Mineralization and Structures

One-half of the structures outlined by this study on the top of the M bed in the Picher field exhibit areally associated mineralization: four synclines and two anticlines. The four synclines exhibit a range in intensity of mineralization which ranges from moderate to intense. Structure number 59 is one which exhibits a co-axial area of associated intense mineralization. Of the two anticlines which exhibit intense mineralization, the best example is structure number 65.

One-half of the fourteen flanks have related mineralization which varies from little to intense in amount. Mined ore generally tends to parallel structural flanks such as shown by structure number 59, but in a few instances mineralization cuts across the flank of the fold such as shown by structure number 60. The two fault-troughs show very closely related mineralization.

3. Quapaw-Baxter Springs field

a. Structures

In the Quapaw-Baxter Springs field, five synclines and four anticlines were outlined by structure contours on the top of the M bed. Two of the synclines are of moderate size but the other three are small. The five synclines are symmetrical, broad and have a northwesterly trend. Two of the anticlines fall in the category of major structures, while the remaining two are of small size. Eleven flanks have been considered in the analysis of the regional structural position of mineralization.

b. Relationship Between Mineralization and Structures

There appears to be little relationship between the regional structure depicted on the top of M bed and the areas of ore mined in the Quapaw-Baxter Springs field, but the synclines show some relationship. One of the synclines exhibits moderate to intense associated mineralization, and two synclines show some mineralization. Only one of the anticlines, structure number 74, shows mineralization which may be related to the nose of that structure.

None of the fold flanks in the Quapaw-Baxter Springs field have associated mineralization. In fact, in two instances mineralization cuts across the flanks. This is well shown by the northwest flank of structure number 75.

4. Melrose field

a. Structures

In the Melrose field one small anticline and one moderate syncline were determined. Both structures are broad, symmetrical and exhibit a northwesterly trend. The flank between the two folds was considered in the study of mineralized areas.

b. Relationship Between Mineralization and Structures

Some mineralization appears to occur along the axes of both folds in the Melrose field.

5. Galena field

a. Structures

In the Galena field three anticlines and three synclines were outlined. The synclines are broad and mostly symmetrical. They are mainly of moderate size in this field but one is small. The anticlines, two of which are of moderate size and one small, exhibit three different shapes: asymmetrical and broad, symmetrical and narrow, symmetrical and broad. Two of the structures show a northeasterly trend in contrast to the others which trend northwesterly. Three flanks between folds were listed.

b. Relationship Between Mineralization and Structures

Of the three synclines in the Galena field two have related mineralization. One anticline exhibits a little areally associated mineralization. One flank shows some mineralization and two exhibit a little mineralization.

6. Joplin field

a. Structures

In the Joplin field there are five structures as shown by the top of the M bed structure contour map. Of these structures, one of the two anticlines, the Joplin anticline, is of major size and the other is small. The sizes of the three synclines are major, moderate and small. All the structures are symmetrical and they trend northwesterly except for one which trends northeasterly. Four flanks were considered.

b. Relationship Between Mineralization and Structures

The three synclines outlined in the Joplin field have related mineralization which varies in intensity from little to intense. The two anticlines have a moderate amount of areally related mineralization. Structure number 86 is a good example of an anticline with associated mineralization. Mineralization is related to three of the four flanks.

7. Oronogo-Webb City-Carterville-Duenweg field

a. Structures

In the Oronogo-Webb City-Carterville-Duenweg field two anticlines and two synclines have been outlined. One of the synclines and one of the anticlines are of major dimensions, and the other two structures are of moderate size. The structures have a northwesterly trend and all but one are symmetrical. Four flanks between the folds were separately considered.

b. Relationship Between Mineralization and Structures

Both synclines but only one anticline in the Oronogo-Webb City-Carterville-Duenweg field exhibit areally associated mineralization. The synclines exhibit some to moderate mineralization; the anticline shows moderate to intense mineralization. Mineralization related to three flanks varies from little to some. Structure number 91 is a good example of a syncline with associated mineralization.

8. Klondike-Smithfield-Carl Junction-Thomas field

a. Structures

In the Klondike-Smithfield-Carl Junction-Thomas field two anticlines and three synclines were shown on the top of the M bed. Only one of the synclines is of major size, and the others are small. They are broad and symmetrical. One anticline is symmetrical and of major dimensions; the other is asymmetrical and small. All of the structures have a northwesterly trend in the field. Four flanks between the folds were listed.

b. Relationship Between Mineralization and Structures

Two synclines and one anticline show little to some mineralization in this field. All of the four flanks have a little associated mineralization.

9. Badger field

a. Structures

In the Badger field one syncline and one anticline have been delineated. Both structures are symmetrical, of moderate size and trend northwesterly. The single flank between the two folds was considered.

b. Relationship Between Mineralization and Structures

Only the syncline in the Badger field has some areally related mineralization. Some mineralization cuts across the single flank.

10. Waco field

a. Structures

One anticline was delineated in the Waco field. It is broad, symmetrical and trends northeasterly.

b. Relationship Between Mineralization and Structures

The single anticline delineated by this study in the Waco field appears to have a moderate amount of areally related mineralization.

E. The M Bed Thickness and Its Relationship To Mineralized Fields

1. Tri-State District

The same data used to prepare the structure contour maps i.e., the elevations of the top and base of the M bed, were used to prepare a map showing the areal variation of the thickness of the M bed (Figure 7). Although an isopachous study of the M bed was not the principal purpose of this study, it has produced what are perhaps the most significant results of the thesis research.

Large variations in the thickness of the M bed are present in the Tri-State district. While the M bed is thicker than 110 feet in some portions of the district, it has been thinned to less than eight feet locally. In some fields, especially those in which the major portion of the mineralization is localized in the M bed, the thinned areas of the M bed are closely related in areal position to the areas in which the principal mineralization occurs. The relationship between mineralization and variation in the M bed thickness is discussed in the following sections for each field in the Tri-State district.

2. Picher field

The Picher field appears on a regional scale to exhibit remarkable variations in the thickness of the M bed, the principal host bed for the ores in that field. Isopachous bands are arranged in a general concentric pattern with the thinnest near the center of the field and progressing to the thickest outside the principal area of mining. The M bed in a large part of the central portion of the Picher mining field is less than 20 feet thick; locally it may be as thin as eight feet. This large central area of very thin M bed, shown by Figure 7, is as much as 2 miles wide and it is about 5 miles long. It displays a prominent northwesterly trend. Several small areas of very thin M bed which lie both to the northwest and to the southeast along the trend of this five mile long area of thin M bed may extend its length to more than eight miles long. The large northwest trending area in which the M bed is less than 20 feet thick is completely encircled by a similarly northwest trending area in which the M bed is 20 to 30 feet thick. This, in turn, is partly enclosed by areas in which the M bed is 40 to 60 feet thick. Thus, on the regional scale of this study, nearly all of the Picher field is encompassed by the M bed which is less than 30 feet thick. Detailed underground study and some drill holes not considered in this study, however, have revealed local patches in the above large area in which the M bed is thicker.

Another area in which the M bed appears to be thinned lies to the southwest of the Picher field and it also trends to the northwest. The paucity of drilling, however, makes the isopachous interpretation of the area very dubious.

Both of the above areas in which the M bed is thinner than 30 feet, in turn, are partly enclosed by zones in which the M bed is 30 to 50 feet thick. These areas lie mostly outside the area of principal mining in the Picher field. More distant from the Picher field the M bed is shown in widely spaced holes to be as much as 80 feet thick.

3. Quapaw-Baxter Springs field

An area of localized mines to the west of the town of Baxter Springs, Kansas, is generally known as the Quapaw-Baxter Springs field. The field was mined principally in the sheet ground beds O, P and Q, which underlie the M bed, but the M bed was mined locally.

There appears to be little or no relationship between mineralized areas and M bed thickness in the Baxter Springs field. The thickness of the M bed in most of the field is about 50 to 80 feet. The reason for this lack of correlation between the M bed thickness and mineralization in the Quapaw-Baxter Springs field likely lies in the fact that most of the mineralization is in the sheet ground beds rather than in M bed.

4. Galena field

An area centered about and particularly to the southwest of the town of Galena, Kansas, has been long known as the Galena field. Aside from the Kansas portion of the Picher field, it has been the most important producing field in Kansas. Production has come from the sheet ground beds as well as from the M bed.

In the central portion of the Galena field, where mining was the most intense, the M bed generally is 30 to 40 feet thick, but locally it is as thin as twelve feet. At the margins of the field, beyond the area of principal mining, the M bed is 40 to 70 feet thick. More distally from the areas of mining available drill hole information is nonexistent. The Galena field appears to exhibit a pattern of zoning of the M bed thickness like that in the Picher field but it appears less distinctive on the map due to the lack of sufficient drill hole information. A 40 feet isopachous line has been drawn only in this field to help outline the area of thin M bed.

5. Joplin field

An area of many small scattered mined areas near the city of Joplin, Missouri, has long been referred to as the Joplin field. In the Joplin field both the M bed and the sheet ground beds were among the important beds mined. Very scant drill hole information available in the Joplin field for this study indicates the M bed to be quite thick, ranging from 65 to 105 feet thick. The lack of regional M bed thinning in the Joplin field may be due to the scattered and relatively small size of the deposits in that field and partly due to the fact that much mineralization there was in the underlying sheet ground beds. The scarcity of drill hole data for the Joplin field further hinders an adequate analysis of that field.

6. Oronogo-Webb City-Carterville-Duenweg field

Insufficient drill hole information is available to adequately analyze the variation in thickness in the Oronogo-Webb City-Carterville-Duenweg field. Several widely spaced drill holes indicate the M bed to have a thickness of the order of 80 feet to more than 100 feet outside the mined area in the field.

7. Melrose Area

Several small mines located about two miles to the south and southwest of Melrose, Kansas, are generally referred to by district geologists as the Melrose area. In the Melrose area the M bed exhibits a large variation in thickness from five feet to 65 feet thick. From this regional study it appears that the thinner areas of M bed may be generally related to the areas of mineralization. Part of the thinning in this area may be due to post-Keokuk erosion for the K and L beds often are missing in this general area (Knox, 1948) but the presence of the Short Creek Oolite locally suggests that most of the M bed in this area may have been present prior to mineralization (E. H. Hare, oral communication).

8. Faulkner Area

Drilling in an area southeast of Faulkner, Kansas, and northwest of Melrose, Kansas, has traversed thicknesses of the M bed which are as thin as ten feet. An area in which the M bed is less than 20 feet thick appears to be generally encircled by an area of 20 to 60 feet M bed thickness, but one hole traversed 104 feet of the M bed. No mining has taken place in the Faulkner area. The areal position of thin M bed in the Faulkner area raises the question as to whether it may be an extension of the large elongated area of very thin M bed six miles distant to the southwest in the Picher field. Such a correlation seems doubtful since the thin M bed in the Faulkner area trends to the northeast and it may have originated principally by post-Keokuk erosion into the M bed.

9. Neutral Area

A moderate amount of drilling has been done within a radius of about four miles of the town of Neutral, Kansas. Very little or no mining has taken place within the area. Many of the drill hole logs available to the writer indicated that the holes had not traversed the entire section of M bed thickness. Those holes which reached the bottom of the M bed indicate its thickness to vary from 30 to 70 feet in the Neutral area.

10. Badger-Klondike-Smithfield-Carl Junction field

A fairly broad area of scattered small mines are included here as the Badger-Klondike-Smithfield-Carl Junction field. Scattered drill hole information for this area indicates a range in M bed thickness from 33 to 90 feet. The density of drill holes is insufficient to bring out any regular areal variation in M bed thickness which may be present.

11. Waco Field

Important mining has taken place along the Missouri-Kansas state line near the town of Waco, Missouri. The area is generally known as the Waco field. Although no information was obtained within the field, thickness data to the west indicate a general increase in thickness westward from the field.

CHAPTER IV

SUMMARY AND CONCLUSIONS

A. Structures On The Top And Bottom of the M Bed

This regional structural study has brought out a large number of structures in the Tri-State district which may have influenced the general location of its zinc-lead mineralization. Mineralization is most closely related to a small number of fault-troughs. Whether these structures were major conduits or simply another type of open structure which was favorable to the deposition from the ore-bearing solutions is not entirely certain.

This study has been unable to ascertain a well-defined preference of the ore-bearing solutions for one type of fold structure as opposed to another. A general preference for synclinal structures, however, seems to be indicated by the data compiled for this study. About two-thirds of the synclines, as contrasted to only about one-third of the anticlines, exhibit areally related mineralization. The larger structures more often appear to have areally related mineralization than do smaller ones. The flanks between folds generally tend less to have areally related mineralization than do either type of fold axis.

The preference of mineralization for synclines more than anticlines suggests that the ore-forming solutions were downward-moving at the time of ore deposition.

B. Thickness Of The M Bed

The M bed exhibits a remarkable range in thickness in the Tri-State district. For the district as a whole it varies in thickness from eight feet to 110 feet. In the Picher field isopachous zones encircle the area of most intense mining and mineralization. Nearly all of the principal mined area in the Picher field exhibits regional thicknesses of the M bed less than 30 feet. In more than one-half of that area the M bed is even less than 20 feet thick. Outward from the main mined area the M bed becomes progressively thicker until it is as much as 80 feet thick.

Similar, but less well defined, zonal patterns of M bed thickness are associated with the Galena, Melrose and possibly Waco fields. Insufficient drilling along with some inadequate drill logs render regional analysis of the variation of the M bed thickness impossible for the other fields at this time.

These large variations of the M bed thickness may have come about in one or more of the following manners: 1) the M bed was deposited as unit whose thickness varied greatly, 2) erosion of the M bed after lithification at unconformity surfaces with accompaning ground water dissolution subjacent to those surfaces caused the M bed to be thinned in many places, and 3) the M bed was thinned by the ore solutions during ore deposition.

The original variations in the M bed thickness are not easily ascertained. In a very general regional manner the

M bed increases in thickness from about 70 to 80 feet in the peripheral unmineralized vicinities of the Picher field to about 110 feet in similar vicinities near Webb City. From the west margin of the Picher field westward the M bed becomes thinner and eventually pinches out due to erosion at the post-Keokuk unconformity.

The presence of the thinner M bed in the mineralized fields rather than in areas distal from mineralization is caused by the solution of the M bed after it was deposited. Evidence that this is the case is shown by the prominent solution chert breccias in the mineralized fields. Additional evidence for the solution activity is the local tilting and collapse of the massive overlying incompetent N bed into areas from which M bed had been removed by solution (D. C. Brockie, oral communication). A point of less certainty, however, is the time of solution of the M bed. Two general times are conceivable. First, the solution of limestone may have been accomplished by the ore-forming solution at essentially the same time at which the ores were deposited. The close relationship between the ore mineralization and the M bed thinning favors this interpretation. The formation by limestone solution of sulfide-bearing jasperoid proves that at least some solution took place during mineralization.

Secondly, the major solution activity may have preceded the main period of ore deposition, thus preparing the host M bed limestone with open spaces which facilitated the ingress of the subsequent mineralizing solutions. In this case the solutions which caused the solution of limestone may have been somewhat different in character from those which deposited the ores. Such limestone-dissolving solutions may have been ground waters associated with any of the various post-M bed unconformity surfaces. The local deep erosion of the post-Keokuk surface (uneven base of the glauconitic, phosphatic, black shaly J bed) through the K and L beds and into the M bed in some mines demonstrates that at least some thinning of the M bed has taken place by erosion. Subsurface ground waters associated with that and later unconformity surfaces probably caused considerable limestone solution similar to that of the ground waters associated with the present surface.

In summary, the thinning of the M bed found associated with fields of mineralization appears to be due partly to erosion and ground water solution at paleo-unconformity surfaces and partly to solution activity of the ore-forming solutions themselves. The relative importance of those two processes in thinning of the M bed is not known.

The northwest trend of the pattern of the M bed thinning in the Picher field does not seem to be congruent with the theory that the northeast trending Miami fault-trough is the prime conduit for the ore-forming solutions.

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APPENDIX 1

TRI-STATE STRUCTURES DETERMINED ON THE BASE OF THE M BED AND THEIR MEASURED CHARACTERISTICS

Number of Structure	Type of Structure	Size (Areal) million square feet	Shape	Strike	Related Minerali-zation	Location of Minerali-zation	Intensity of Minerali-zation
Picher Field - Southeastern Portion							
1	Fault	48.8	-	N. 40° E.	x	Along trough	Intense
	SW Flank	-	-	-	-	-	-
2	Anticline	48.9	Symmetrical	N. 25° W.	-	-	-
	Flank	-	-	-	-	-	-
3	Syncline	24.9	Symmetrical	N. 15° W.	x	Trough	Intense to
	Flank	-	-	-	x	Along	Moderate
4	Anticline	69.7	Symmetrical	N. 14° E.	x	Nose	Moderate
	Flank	-	-	-	-	Across	Little to Moderate
5	Syncline	17.5	Asymmetrical	N. 13° W.	x	Nose	Some
	Flank	-	-	-	-	Across	Moderate
6	Anticline	48.9	Symmetrical	N. 5° W.	-	Across	Little to Some
	Flank	-	-	-	x	Along	Little

7	Syncline	30.5	Symmetrical	N. 30° W.	x	Trough	Moderate to Intense
	NE Flank	-	-	-	x	Along and Across	Some to Moderate
8	Anticline	37.1	Symmetrical	N. 25° E.	x	Crest	Moderate
	Flank	-	-	-	-	-	-
9	Syncline	34.9	Symmetrical	N. 26° E.	x	Nose	Little to Moderate
	NE Flank	-	-	-	-	-	-
Picher field - Northwest Portion							
10	Anticline	18.3	Symmetrical	-	-	-	-
	SW Flank	-	-	-	-	-	-
11	Anticline	41.8	Symmetrical Broad	N. 52° W.	-	-	-
	Flank	-	-	-	-	-	-
12	Syncline	3.4	Symmetrical	-	-	-	-
	Flank	-	-	-	-	Across	Little
13	Anticline	55.0	Asymmetrical	N. 11° E.	x	Crest	Intense
	NE Flank	-	-	-	x	Across Along	Intense
	NW Flank	-	-	-	-	-	-

14	Anticline	10.5	Asymmetrical	N. 5° E.	x	Crest	Intense
	NE Flank	-	-	-	x	Along	Intense to Moderate
15	Fan Fold	34.8	-	N. 54° W.	-	-	-
16	Anticline	20.9	Symmetrical Very Broad	E. - W.	-	-	-
	N Flank	-	-	-	-	-	-
17	Anticline	34.8	Symmetrical	N. 19° W.	x	Crest	Some
	Flank	-	-	-	-	-	-
18	Syncline	8.5	Symmetrical Narrow	N. 9° W.	x	Nose	Moderate
	Flank	-	-	-	-	-	-
19	Anticline	13.1	Symmetrical	N. 22° W.	-	-	-
	NE Flank	-	-	-	-	-	-
	W Flank	-	-	-	x	Across Along	Moderate to Intense
20	Anticline	25.5	Asymmetrical	N. 22° W.	-	-	-
Melrose field							
21	Anticline	31.4	Symmetrical Broad	N. 22° W.	-	-	-
	Flank	-	-	-	-	-	-

22	Syncline	19.8	Symmetrical Narrow	N. 33° W.	x	Trough	Some
Quapaw-Baxter Spring field							
23	Syncline	27.9	Symmetrical Broad	N. 75° W.	-	-	-
	Flank	-	-	-	-	-	-
24	Anticline	13.1	Symmetrical	N. 83° W.	-	-	-
	Flank	-	-	-	-	-	-
25	Syncline	10.4	Symmetrical	E. - W.	-	-	-
	Flank	-	-	-	-	-	-
26	Anticline	10.5	Symmetrical	E. - W.	-	-	-
	N Flank	-	-	-	x	Along	Moderate to Intense
27	Anticline	6.9	Symmetrical Broad	N. 71° E.	-	-	-
Galena field							
28	Syncline	41.9	Symmetrical	N. 26° W.	x	Trough	Some
29	Syncline	48.8	Symmetrical	E. - W.	x	Trough	Some
	N Flank	-	-	-	-	-	-

30	Anticline	15.7	Symmetrical	N. 83° W.	-	-	-
	Flank	-	-	-	-	-	-
31	Anticline	10.5	Symmetrical	N. 70° W.	-	-	-
	Flank	-	-	-	-	-	-
32	Syncline	10.5	Symmetrical Broad	N. 21° W.	-	-	Little
	Flank	-	-	-	-	-	-
33	Anticline	27.9	Symmetrical	N. 48° W.	-	-	-
	Flank	-	-	-	-	-	-
34	Anticline	31.4	Symmetrical	N. 30° E.	-	-	-
	Flank	-	-	-	-	-	-
35	Syncline	38.4	Asymmetrical	N. 30° E.	x	Trough	Some
Joplin field							
36	Syncline	23.6	Symmetrical	N. 18° W.	x	Trough	Some
	Flank	-	-	-	x	Along	Moderate
37	Anticline	67.0	Symmetrical Very Broad	N. 22° W.	-	-	Some Moderate
	Flank	-	-	-	x	Along	Intense

38	Syncline	21.8	Asymmetrical Very Broad		x	Trough	Moderate
	Flank	-	-	-	-	-	-
39	Anticline	15.7	Symmetrical	N. 16° W.	x	-	Little
	Flank	-	-	-	-	-	-
40	Syncline	31.4	Symmetrical	N. 62° W.	-	-	-
	Flank	-	-	-	-	-	-
41	Anticline	34.8	Symmetrical	N. 63° W.	-	-	-
Oronogo-Webb City-Carterville-Duenweg field							
42	Anticline	94	Symmetrical	N. 20° W.	x	Crest	Moderate to Intense
43	Syncline	39.2	Symmetrical	N. 16° W.	x	Trough	Moderate to Intense
	Flank	-	-	-	x	Along	Little Some
44	Anticline	34.9	Symmetrical	N. 52° W.	x	Crest	Intense to Moderate
	Flank	-	-	-	x	Along	Moderate
45	Syncline	10.4	Symmetrical	N. 38° W.	x	-	Moderate
	E Flank	-	-	-	-	Across	Moderate to Little

Klondike-Smith-Carl Junction-Thomas field							
46	Anticline	19.6	Symmetrical Broad	N. - S.	x	Crest	Some
	Flank	-	-	-	-	-	-
47	Syncline	17.4	Symmetrical Narrow	N. 43° W.	-	-	-
	Flank	-	-	-	-	-	-
48	Anticline	48.9	Symmetrical Narrow	N. 52° W.	-	-	-
	Flank	-	-	-	x	Along	Little
49	Syncline	48.9	Asymmetrical Shallow	N. 35° W.	x	Trough	Little
	Flank	-	-	-	-	-	-
50	Anticline	16.3	Symmetrical Broad	N. 15° E.	-	-	-
	Flank	-	-	-	-	-	-
51	Syncline	21.8	Asymmetrical Broad	N. 24° E.	x	-	Little
Badger field							
52	Anticline	17.4	Symmetrical	N. 60° W.	-	-	-
	Flank	-	-	-	-	-	-

53	Syncline	14.0	Symmetrical		-	-	-
Waco field							
54	Syncline	2.6	Symmetrical	N. 68° W.	-	-	-

APPENDIX 2

TRI-STATE STRUCTURES DETERMINED ON THE TOP OF THE M BED AND THEIR MEASURED CHARACTERISTICS

Number of Structure	Type of Structure	Size (Areal) million square feet	Shape	Strike	Related Mineralization	Location of Mineralization	Intensity of Mineralization
Picher field - Southeastern Portion							
57	Fault	48.8	-	N. 36° E.	x	Within the trough	Some
	SW Flank	-	-	-	x	Along	Some
58	Anticline	34.8	Asymmetrical	N. 36° W.	x	Nose and Crest	Intense to Moderate
	Flank	-	-	-	x	Along	Intense to Moderate
59	Syncline	36	Symmetrical Broad	N. 23° W.	x	Trough	Intense
	Flank	-	-	-	x	Along	Intense
60	Anticline	18.3	Symmetrical Very Broad	N. 6° E.	-	-	-
	Flank	-	-	-	-	Across	Moderate
61	Syncline	10.5	Symmetrical Broad	N. 10° W.	x	Trough	Moderate
	NW Flank	-	-	-	-	-	-

Picher field-Northwestern Portion

	SW Flank	-	-	-	-	-	-
62	Anticline	13	Asymmetrical	N. 50° W.	-	-	-
	Flank	-	-	-	x	Along	Little
63	Anticline	31.4	Symmetrical Broad	N. 36° W.	x	Trough	Moderate
	Flank	-	-	-	-	-	-
64	Syncline	11.3	Symmetrical Broad	N. 20° W.	x	Trough	Moderate
	Flank	-	-	-	x	Along	Moderate
65	Anticline	45.4	Symmetrical Narrow	N. 42° W	x	Crest	Intense
	Flank	-	-	-	x	Along	Intense to Moderate
66	Related to Fault	39.2	-	N. 35° E.	x	Within the trough	Some
67	Anticline	6.9	Symmetrical Broad	N. 7° E.	x	Crest	Intense
	Flank	-	-	-	x	Along	Moderate
68	Syncline	8.7	Asymmetrical Broad	N. 2° E.	x	Trough	Moderate to Intense
	Flank	-	-	-	-	Across	Some

69	Anticline	26.6	Symmetrical Narrow	N. 42° W.	-	-	-
	Flank	-	-	-	-	-	-
70	Syncline	14.4	Asymmetrical Broad	N. 15° E.	-	-	-
	SW Flank	-	-	-	-	-	-
Quapaw-Baxter Springs field							
71	Syncline	7.9	Symmetrical	N. 27° W.	x	Nose	Some
	Flank	-	-	-	-	-	-
72	Anticline	24.4	Symmetrical	N. 36° W.	x	Nose	Little
	Flank	-	-	-	-	-	-
73	Syncline	33.5	Symmetrical	N. 36° W.	-	-	-
	Flank	-	-	-	-	-	-
74	Anticline	20.9	Symmetrical	N. 72° W.	x	Nose	Little
	Flank	-	-	-	-	-	-
75	Syncline	18.3	Symmetrical Very Broad	N. 72° W.	x	Trough	Moderate to Intense
	NW Flank	-	-	-	-	Across (?)	Moderate

76	Anticline	94	Symmetrical Broad	N. 46° W.	-	-	-
	Flank	-	-	-	-	-	-
77	Syncline	10.5	Symmetrical	N. 42° W.	x	Nose	Some
77a	Anticline	52.8	Symmetrical Narrow	N. 44° W.	-	-	-
	Flank	-	-	-	-	-	-
78	Syncline	36.4	Symmetrical	N. 38° W.	-	-	-
	NE Flank	-	-	-	-	-	-
Galena field							
	NW Flank	-	-	-	-	-	-
79	Syncline	52.3	Symmetrical Very Broad	N. 84° W.	x	Trough	Moderate
	Flank	-	-	-	x	Along	Some
80	Anticline	43.5	Symmetrical Narrow	N. 87° W.	-	-	-
	Flank	-	-	-	x	Along	Some
81	Syncline	5.2	Asymmetrical Broad	N. 64° W.	x	Trough	Some
	SW Flank	-	-	-	-	-	-

82	Anticline	31.4	Asymmetrical Broad	N. 49° W.	-	-	-
	Flank	-	-	-	-	-	-
83	Anticline	20.9	Symmetrical Broad	N. 47° E.	x	Crest	Little
	Flank	-	-	-	-	-	-
84	Syncline	6.3	Symmetrical Broad	N. 47° E.	-	-	-
	NE Flank	-	-	-	-	Along (?)	Little
Joplin field							
	NW Flank	-	-	-	-	-	-
85	Syncline	11	Symmetrical Very Broad	N. 32° W.	x	Trough	Intense to Moderate
	Flank	-	-	-	x	Along	Moderate
86	Anticline	73	Symmetrical Broad	N. 23° W.	x	Nose	Moderate
	Flank	-	-	-	x	Along	Moderate
87	Syncline	27.8	Symmetrical	N. 52° W.	x	Trough	Moderate
88	Anticline	20.9	Symmetrical Narrow	N. 10° E.	x	Crest	Little to Moderate
	Flank	-	-	-	x	Crest	Little to Moderate

89	Syncline	41.7	Symmetrical Broad	N. 44° W.	x	Trough	Little
Oronogo-Webb City-Carterville-Duenweg field							
90	Anticline	27	Symmetrical Broad	N. 30° W.	-	-	-
91	Syncline	31.4	Symmetrical Broad	N. 30° W.	x	Trough	Moderate
	NW Flank	-	-	-	x	Along	Little
92	Syncline	51.1	Symmetrical	N. 42° W.	x	Trough	Some
93	Anticline	53.2	Asymmetrical Broad	N. 8° E.	x	Nose	Moderate to Intense
94	Anticline	76.6	Symmetrical Broad	N. 75° W.	-	-	-
95	Syncline	24.4	Symmetrical Broad	N. 46° W.	x	Trough	Some
Klondike-Smith field-Carl Junction-Thomas field							
	SW Flank	-	-	-	-	-	-
96	Anticline	17.5	Symmetrical Broad	N. 22° W.	-	-	-
	Flank	-	-	-	-	-	-

VITA

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He entered the Faculty of Science, Baroda University, Baroda in June, 1950. In March 1956, he completed his requirements for the degree of Bachelor of Science in Chemistry. In March 1958, he completed the requirements for a special Bachelor of Science degree in Geology.

After graduation, he joined the University of Baroda, India, initially as a Research Assistant and subsequently as an Instructor in Geology. During this period he also worked as a sales organizer for P. M. Patel Company, planning and executing sales of such mineral commodities as calcite, quartz, limestone and bentonite. In the autumn of 1964, he enrolled at the University of Missouri at Rolla as a candidate for an M. S. degree in Geology.